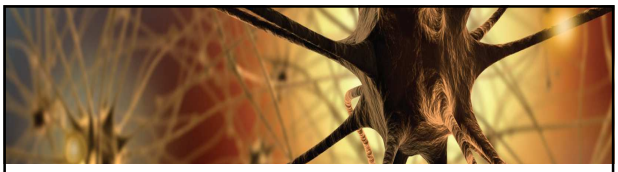

Artificial Intelligence Applications in the E&P Industry and an example of Short-Term Production Prediction Using Neural Networks

SPE Webinar

Luigi Saputelli, PhD

Society of Petroleum Engineers

Petroleum Data-Driven Analytics (PD²A) Technical Section

Agenda

- Main challenges in E&P Industry
- What is AIPA?
- Petroleum Data-Driven Analytics (PD2A) Technical Section
- AIPA: State of the Art
- Survey
  - AIPA in Internet
  - Level of Awareness
  - Who is using AIPA in E&P Industry?
  - Most common solutions
  - Impact in E&P Industry
  - Level of Available Information
- Final Remarks

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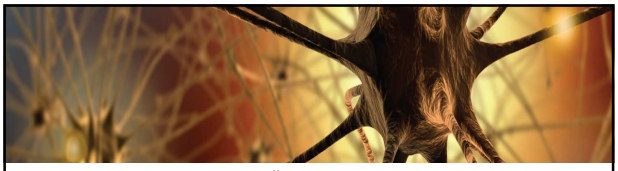

Poll Question #1

What is your primary discipline?

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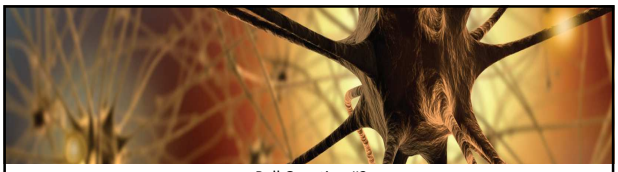

Poll Question #2

What is your primary role?

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State of the Art of Artificial Intelligence and Predictive Analytics in the E&P Industry: A Technology Survey

Paper SPE 150314

C. Bravo, Halliburton; L. Saputelli, Frontender; F. Rivas and A. Pérez, ULA; M. Nikolaou, University of Houston; G. Zangl, Fractured Reservoir Dynamics; N. de Guzman, Intelligent Agent Corp; S. Mohaghegh, West Virginia University and G. Nunez, Schlumberger

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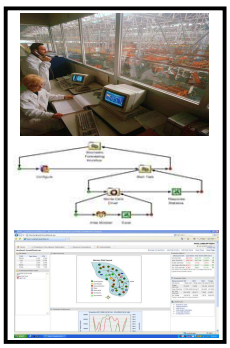
Technology Challenges

- The production market shares many challenges with manufacturing and the process industry
- Hundreds to thousands of data sources
  - Each application or database has its own structure
  - No common definitions or models
- Estimates of up to 16,000 technical applications in use
  - Spreadsheets add many thousands more
  - Manual connections for integrated workflows are nearly impossible
- Conflicting priorities and constraints impede optimizing the entire value chain
- Engineers spend 80% of their time gathering data and 20% of their time analyzing the data and making decisions



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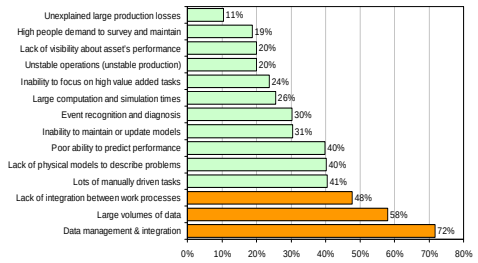
From SPE 150314

Main challenges in Information Management at the E&P Industry



Main challenges in E&P industry are related with the data management & integration

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What is Artificial Intelligence and Predictive Analytics?

- "Artificial Intelligence and Predictive Analytics" (AIPA) has been used to embed AI techniques into a broader set of techniques aimed at processing and data analysis, business process automation, and advanced visualization.
- In addition to the classical techniques of AI, AIPA includes data mining, automatic process control, workflow automation, and virtual environments, among others.
- Members of SPE involved in AI created an AIPA subcommittee (now PD2A) in 2009 as a part of the SPE Digital Energy Technical Section.

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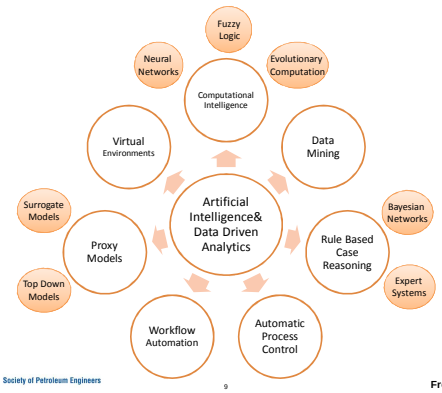
AIPA: State of the Art



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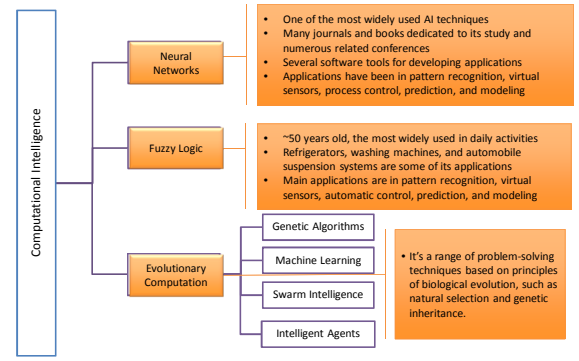
AIPA: State of the Art



- One of the most widely used AI techniques
- Many journals and books dedicated to its study and numerous related conferences
- Several software tools for developing applications
- Applications have been in pattern recognition, virtual sensors, process control, prediction, and modeling

- ~50 years old, the most widely used in daily activities
- Refrigerators, washing machines, and automobile suspension systems are some of its applications
- Main applications are in pattern recognition, virtual sensors, automatic control, prediction, and modeling

- It's a range of problem-solving techniques based on principles of biological evolution, such as natural selection and genetic inheritance.

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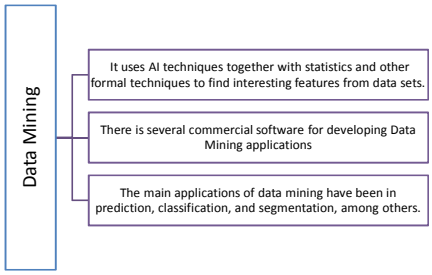
AIPA: State of the Art



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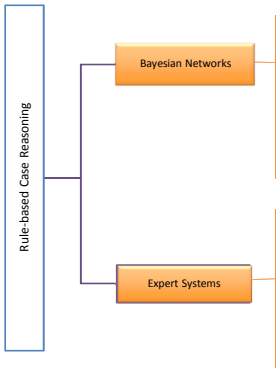
AIPA: State of the Art



- Bayesian networks are computer models of probabilistic systems—that is, real-world systems operating under uncertainty.
- They are used in diagnostics in process control, implemented in expert systems for probabilistic decision support, and used for optimization.
- Standalone software tools are available.
- Most implementations are done in custom development projects

- Oldest artificial intelligence technique according to applications development
- It was the most widely used AI technique during the 1970s and 1980s
- Nowadays is a very well-consolidated area
- There are many expert system software packages for developing applications
- Expert systems have had diverse applications in health, industry, finance, security, and fault detection and diagnosis, among other areas.

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AIPA: State of the Art

Automatic Process Control

- Most studied area into AIPA techniques
- It is not an AI technique but can use AI in some schemes.
- Automatic process control includes classical, robust, adaptive, model predictive, and intelligent, among others.
- There are numerous journals and books on the subject and a variety of conferences concerning this area.
- There is abundant computer software and devices created for developing applications for either educational or industrial use.
- Tools for activities that are essential for automatic control, such as system identification, modeling, prediction, and optimization are well developed.

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AIPA: State of the Art

Proxy Models

Surrogate Models

- Are developed using AIPA technologies
- May be considered as a form of proxy models that have recently been introduced.
- SRM are distinguished from proxy models since they do not approximate the problem.
- They are built to accurately replicate reservoir simulation models for fast track analysis and quantification of uncertainties.

Top down Models

- Are reservoir simulation models that are developed using measured field data such as well location, well trajectories, well logs, core analysis and well tests, seismic data and Production and injection rates.
- Since TDM is built using field data it is only applicable to brown fields.
- TDM attempt to deduce physics from measured field data

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AIPA: State of the Art

Workflow Automation

- Set of techniques and tools that allow the integration of several data sources and applications and the collaboration among members of a team, though a well-defined sequence of activities in order to automate operations in an enterprise.
- Complex event management tools provide techniques for monitoring activities and for responding dynamically to abnormal conditions.
- In the E&P industry, WFA has become a major driver of the DOF.
- Nowadays WFA is one of the areas of major interest in the industry

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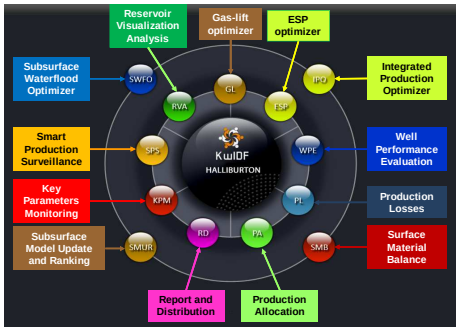
KOC's Workflows Example



- Workflows are automated task sequence to retrieve, filter, validate and process data to achieve a predetermined outcome
- Surveillance analysis and optimization workflows
- Petroleum engineers tasks are streamlined
- Artificial Intelligence component to anticipate and enable smarter decisions

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AIPA: State of the Art

Virtual Environments

- Physical or digital spaces where companies try to mimic remote operations
- Provide engineering support and subsurface interpretation
- The ability to make decisions is enhanced because of the use of a collaborative environment
- Brings together experts from different locations, computers and data from different networks and domains, as well as real-time predictive analytical and expert systems.
- Applications: remote drilling operations support, production surveillance and optimization support, operator training simulators, geology and geophysics interpretation, logistics and combinations of the previous.

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Survey

Purpose: capture the level of AIPA knowledge in the industry, the most common application areas, and the expectations of the users from AIPA-based solutions

Motivation: This work aims to be a guide for personnel responsible for production and asset management on how AIPA-based applications can add more value and improve their decision making

Audience: Developed and conducted on the broad community of SPE professionals. Survey was sent out during October 2011 and 612 responses were received.

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Survey

Structure:

The survey was composed of thirteen questions about:

- Information management and analysis challenges in the industry
- Level of knowledge about AIPA techniques
- Most commonly applied AIPA techniques
- Application areas of AIPA techniques
- Level of perceived value and areas of impact of AIPA techniques
- Perceived level of knowledge available about AIPA techniques
- Perceived maturity of AIPA techniques
- AIPA commercial tools
- Demographic information

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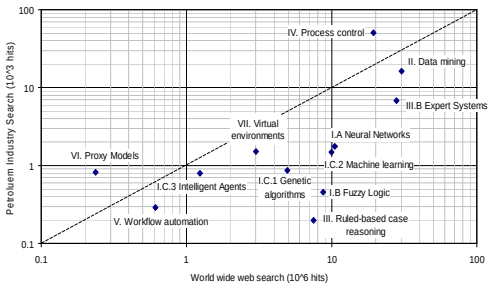
AIPA in Internet



Process control, data mining, and expert systems are the top three AIPA technologies in both the petroleum industry and WWW trends, whereas **proxy models and workflow automation** are the bottom two most popular technologies in both sectors

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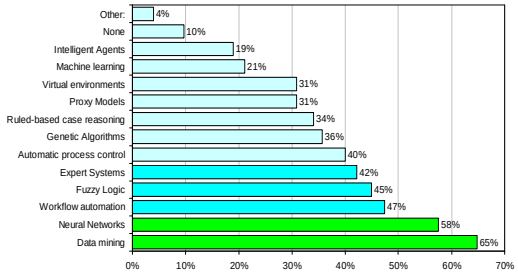
Poll Question #3 (Check all that apply)

Which of the following techniques are you aware of?

- ☐ Data mining
- ☐ Neural Networks
- ☐ Intelligent Agents
- ☐ Machine Learning
- ☐ Virtual Environment
- ☐ Proxy Models
- ☐ Ruled-based case reasoning
- ☐ Genetic algorithms
- ☐ Automatic process control
- ☐ Expert systems
- ☐ Fuzzy Logic
- ☐ Workflow automation

Level of Awareness



Data mining and **Neural Networks** are the AIPA applications in the petroleum industry that individuals are more aware of. Emergent techniques, like **Intelligent Agents and Machine Learning,** are less known in the E&P industry

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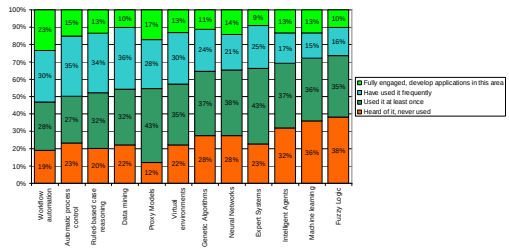
Level of Awareness



WFA and Proxy Models are the techniques in which there are more users fully engaged
More frequently used techniques are **Data Mining and Automatic Process Control**

Fuzzy Logic, Machine Learning and Intelligent Agents have the higher percentage of "never used" answers

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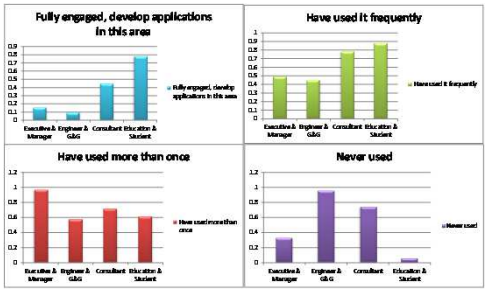
Who is using AIPA in the E&P Industry?



Consultants and Education professionals are the users that more commonly use the AIPA techniques
There is 34% of **Engineers or G&G** that never have used the AIPA techniques

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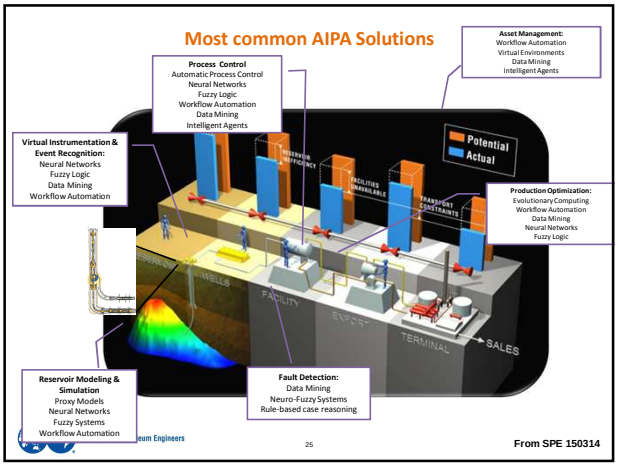
Most common AIPA Solutions



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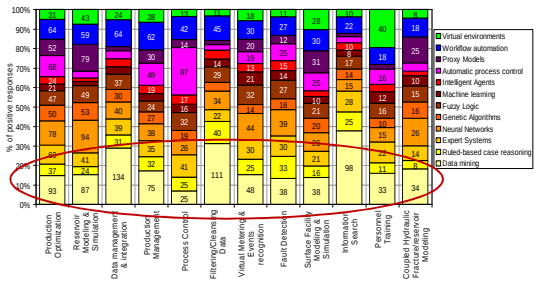
Most common AIPA Solutions



Data mining is the most used technique, mainly in Data Management & Integration, Data Filtering & Cleansing and Information Search

Neural Networks are used mainly in Production Optimization, Reservoir Simulation and Virtual Metering

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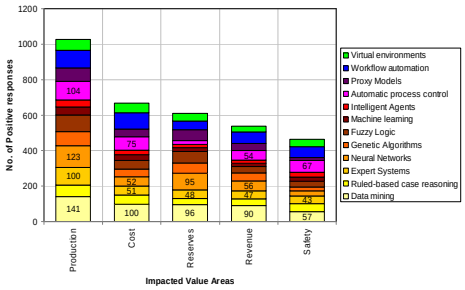
Impact in the E&P Industry



Main impact of AIPA is perceived in **Production**

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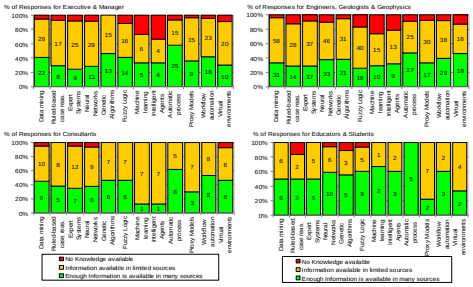
Perceived level of available knowledge



Most of professionals think that there are limited information sources about AIPA
Consultants and **Educators & Students** perceive that there is enough information available about AIPA

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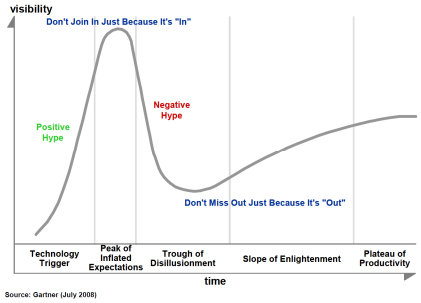
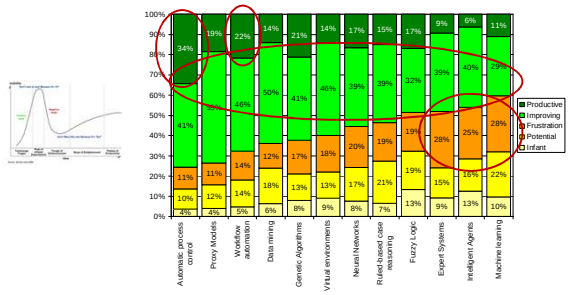
The Hype Curve



Source: Gartner (July 2008)

Perceived level of maturity



- **Automatic process control and WFA** are perceived as in **"Productive"** stage
- **Expert Systems, Intelligent Agents and Machine Learning**, have a high level of **frustration**
- Most techniques are considered to be in **"improvement"**

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AIPA Survey Final Remarks

- AIPA techniques has been used for more than two decades as a development tool for solutions in several areas of the E&P industry. Nevertheless, AIPA applications have not been consolidated as standard solutions in the industry, and **most common applications of AIPA still are case studies and pilot projects.**
- With the implementation of digital oilfield (**DOF**) programs in several oil and gas companies, **application of AIPA technologies seems to be increasing**.
- Application of heuristic techniques in the **processing and analysis of data, physical modeling, processes prediction, and optimization**, is often in **DOF implementations**.
- The **availability of commercial solutions** can be an important factor to increase the penetration of AIPA in the industry
- To increase AIPA penetration and reap expected benefits, **there is a need for**:
  - **Illustrative literature,**
  - **Clear accounts of case histories,**
  - **Collaboration programs between industry and academia and**
  - **Industrially hardened software tools**.

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Short-term production forecasting and optimization example

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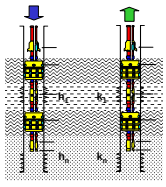
Problem Definition and Motivation

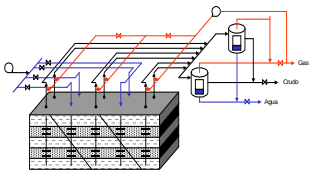
Injector - Producer Profile Mngt.

- Control undesired fluid production
- Exploit efficiently multilayer horizons
- Characterize inter-well relationships
- Maximize reserves and production
- Control from surface measurement



Field-Wide Management

- Optimize production bottle-necks
- Commingle multilayer reservoirs
- Minimize production costs
- Maximize reserves and production
- Control from surface measurement



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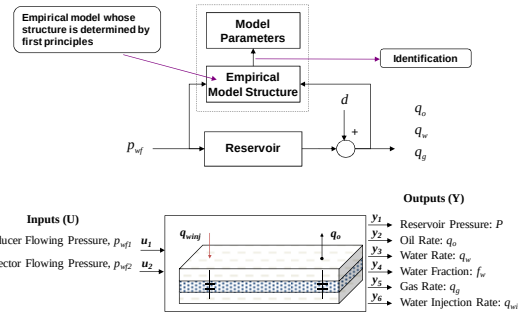
From SPE 84064

Solution Approach

- ***Model based control system*** used to continuously optimize three-phase fluid migration in a multi-layered reservoir
- A hierarchical ***data-driven model*** that is continuously updated with collected production data.
- A self-learning and self-adaptive engine that continuously ***predicts the best operating points*** of a hydrocarbon-producing field, while integrating subsurface elements surface facilities and constraints (business, safety, quality, operability).

Model Identification



From SPE 84064

Reservoir Flow and Pressure Modeling

Oil, water and gas flow and pressure as linear functions of flowing pressure

Proposed IPR for continuous monitoring

$$q_o^k = a_0 + a_1 \times p_e^k + a_2 \times p_{wf}^k + a_3 \times \left(p_{wf}^k\right)^2$$
$$q_w^k = b_0 + b_1 \times p_e^k + b_2 \times p_{wf}^k + b_3 \times \left(p_{wf}^k\right)^2$$
$$q_g^k = c_0 + c_1 \times p_e^k + c_2 \times p_{wf}^k + c_3 \times \left(p_{wf}^k\right)^2$$

Proposed Pressure Modeling for continuous monitoring

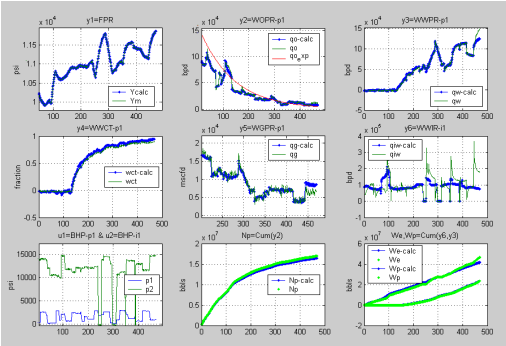
$$\left(\overline{p}\right)^k = \left(\overline{p}\right)^{k-1} + d_1 + d_2 \cdot p_{wf1}^k + d_3 \cdot \left(p_{wf1}^k\right)^2 + d_4 \cdot p_{wf2}^k + d_5 \cdot \left(p_{wf2}^k\right)^2$$

Proposed Pressure Drop Modeling for Continuous Monitoring

$$\left(p_{wf}{}^k - p_{th}{}^k\right) = l_1 q_o^k + l_2 q_w^k + l_3 q_g^k + l_4 \left(q_o^k\right)^2 + l_5 \left(q_w^k\right)^2 + l_6 \left(q_g^k\right)^2$$

From SPE 84064

Predictions Using Empirical Structured Mdels



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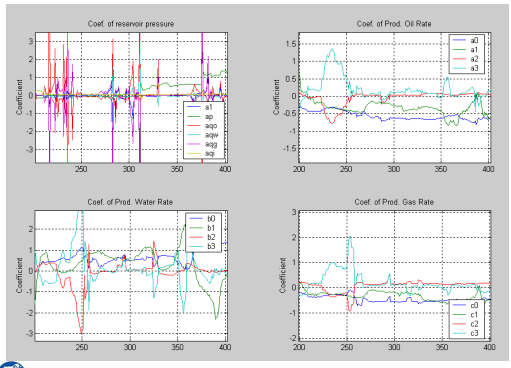
Coefficients Using Empirical models



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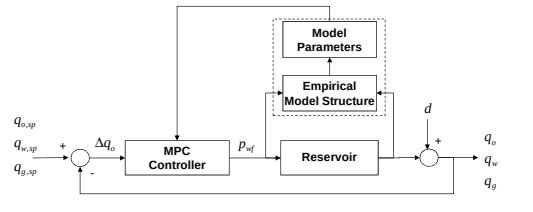
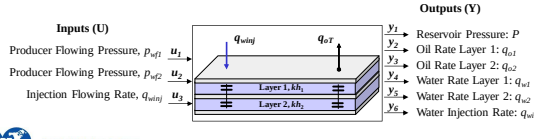
From SPE 84064

Self-learning Reservoir Management: Control





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MPC minimizes future prediction error while satisfying input constraints

Model Predictive Control

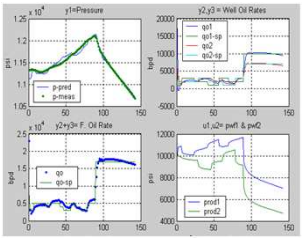
At time ***k*** future predictions of the output ***y*** can be made as

$$\hat{y}_{k+n+j|k} = \sum_{i=n+1}^{n+N} h_i u_{k+n+j-i} + \hat{d}_{k|k} \quad \text{where} \quad \hat{d}_{k|k} = y_k - \sum_{i=n+1}^{n+N} h_i u_{k-i}$$

Minimization Problem to solve

$$\begin{bmatrix} \min \left\{ \sum_{j=1}^{p} \left(\hat{y}_{k+n+j|k} - y^{sp} \right)^2 + R \sum_{j=1}^{m} \Delta u^2_{k+j-1|k} \right\} \\ s.t. \\ y_{\min} \le \hat{y}_{k+n+j|k} \le y_{\max} \qquad j = 1, \cdots, p \\ u_{\min} \le u_{k+j-1|k} \le u_{\max} \qquad j = 1, \cdots, m \\ u_{k+i|k} = u_{k+m-1|k} \qquad i = m, \cdots, p-1 \end{bmatrix}$$

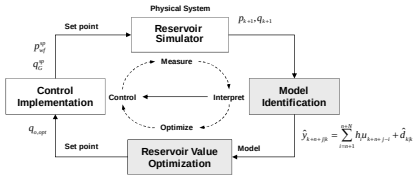
- Controls operation while optimizing performance
- Done over a receding or moving horizon
- Requires a setpoint from an upper level



Set Point Tracking Example
All Variables normalized so that They have zero mean and Std. Dev = 1

Continuous self-learning optimization decision engine

New Self-learning Reservoir Management Technique



LP Optimization Loop

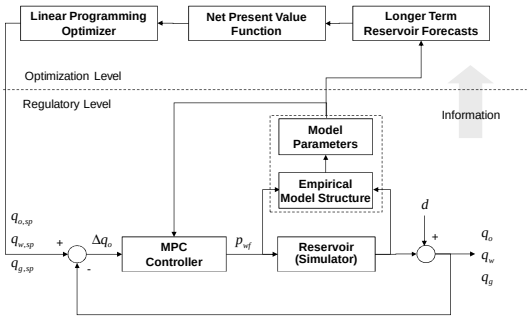
$$\max_{q_o, q_w, q_g} \left\{ \mathbf{NPV} = \sum_{1}^{N} f\left(q_o, q_w, q_g, \$, \Delta T\right) \right\}$$

$$\text{s.t.} \begin{cases} p_{\min} \le p_{k+p,k} \le p_{\max} \\ q_{\min} \le q_{k+p} \le q_{\max} \end{cases}$$

$$\Leftrightarrow \{\hat{q}_{o,opt}, \hat{q}_{g,opt}, \hat{q}_{w,opt}$$

Upper optimization layer passes the best operating point to lower layer

Multilevel Reservoir Control Model

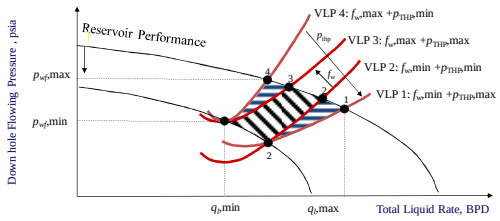


Best operating point (LP) problem subject to well constraints

Linear Optimization Problem

$$\max_{q_o, q_w, q_g}\left\{\mathbf{NPV} = \sum_{1}^{N} f\left(q_o, q_w, q_g, \$, \Delta T\right)\right\}$$

$$NPV = \sum_{k=1}^{N} \frac{\left[\left(q_o^k P_o + q_g^k P_g - q_{wp}^k C_{wp} - q_{wi}^k C_{wi}\right)\Delta T_k - I_T^k - C_F^k\right]\left(1-r^k\right)}{\left(1+i\right)^{\frac{k\cdot\Delta T_k}{365}}}$$



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Attempt to solve a significant reservoir management challenges

Injector-producer Management Problem Results

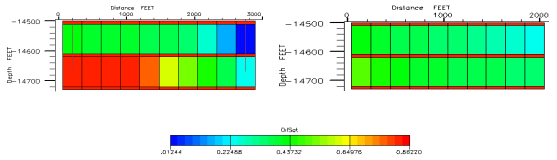
Experimental Base: History-matched Model from El Furrial, HPHT, deep onshore, light oil, 2000 days

Base Case No control

- Early water irruption
- High water cut reduced well's vertical lift
- Further recovery possible at a greater cost

Controlled Case

- Water irruption detected and controlled
- Zone shut off permitted better well's vertical lift
- Recovery accelerated at a minimum cost



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More complex optimization with no obvious results

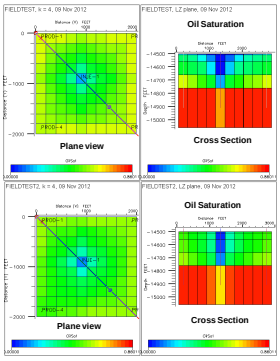
Field-wide Management Problem Results

Base Case No control

- Early water irruption
- High water cut reduced well's vertical lift
- Further recovery possible at a greater cost

Self-Learning Case

- Water irruption detected and controlled
- Zone shut off permitted better vertical lift
- Recovery accelerate at a minimum cost



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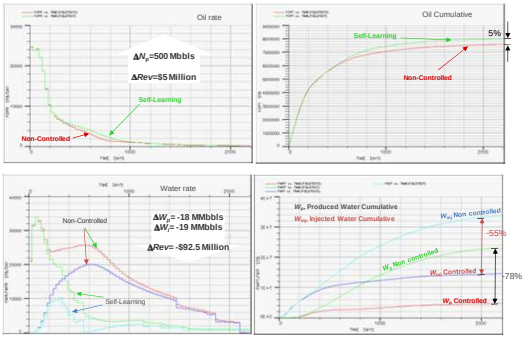
Clear benefits from extra little oil but with a lot less effort.

Field-wide life cycle comparison Results



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Summary & Conclusions

- Multilevel self-tuned reservoir management architecture
  - Upper level calculates the optimum operating point
  - Based on NPV
  - Optimum set point passed to underlying level
- Feasibility of the method demonstrated through a case study
  - Reservoir performance continuously optimized by an adaptive self-learning decision engine
  - Method capitalizes on available remotely actuated devices
- Algorithm feasible for downhole implementation
  - Impart intelligent to downhole and surface actuation devices

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